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JET ENGINE TEST STRATEGY - PROGRAM OVERVIEW AND OBJECTIVES

Written Presented by Ron Howe for Autotestcon 2000

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Abstract

JET Engine Test Strategy (JETS) is an innovative program for improving existing Air Force jet engine test cells. This paper describes the key elements of the JETS and discusses the phased approach for its implementation and realization of the benefits. The proposed system components for implementation of JETS benefits are contained in the Automated Jet Engine Test System (AJETS), which includes the instrumentation system, throttle control, engine-specific test programs, and a network. Charts and photos are used to illustrate current and projected features and benefits of JETS.

INTRODUCTION

Background

Until the early '60s, jet engine testing consisted of techniques and procedures that were, for the most part, an extension of those methods developed for testing reciprocating engines. Testing focused on verification of critical parameters, such as oil pressure and engine revolutions per minute (RPM). Manual test procedures evolved over the next twenty years. Jet engine testing further evolved with introduction of Engine Test/Trim Analysis System (ETTAS). Recent advances in computers and telecommunications have enabled benefits of improved testing and reduced operating and support costs. As the approach to implement upgrades to existing test cell instrumentation, a Commercial Operations and Support Savings Initiative (COSSI) was undertaken. COSSI is implemented as a cost-sharing initiative where benefits of the system are demonstrated as part of a demonstration phase. For JETS the demonstration phase is designated as Phase I.

Objectives

The Jet Engine Test Strategy uses the interfaces enabled by modern computers and telecommunications to improve signal quality in the engine test cell, implement engine diagnostics and prognostics, and share data and propulsion resources for improved performance and cost during the life cycle of the jet engine. Improving test cell data quality and incorporating a network to share data are expected to result in improved engine safety, extended time on wing, reduced support costs for the test cell, and reduced environmental impact.

The primary initiatives that are being introduced in this program are improved sensor and signal quality, engine prognostics, streamlined Test Program Set (TPS) development, and decreased overall support costs. Improved sensor and signal quality are to be achieved by increasing data acquisition rates and accuracy, implementing sensor validation algorithms, and capturing the signal as close to the engine as practical. Prognostic algorithms are to be applied for a specific engine Type, Model, and Series (TMS), by retrieving and analyzing archived data from the host computer. A structured approach for requirements definition and use of a generic TPS will yield benefits of decreased TPS development time. By implementing the improvements in the previously described areas, engine support costs are projected to be reduced in several cost categories

Overall System Benefits

The projected overall system benefits are as follows:

1) Reduce unscheduled engine removals
2) Reduce fuel used during test
3) Reduce manpower to perform testing
4) Reduce manpower requirements for Precision Measurement Equipment Laboratory (PMEL)
5) Reduce time for testing
6) Reduce out year sustainment cost
7) Extend life on wing through accurate prediction of impending component failures

To achieve these system benefits the AJETS tester configuration must meet or exceed the following requirements:

1) Provide fully automated, closed-loop testing of all Air Force engines
2) Significantly reduce support costs in the out years through implementation of universal engine test concepts
3) Provide improved savings-to-investment ratios through the maximum use of data trending, diagnostics, and prognostics
4) Provide for automatic, recurring, system level, facility self-test and calibration control
5) Provide maximum support of environmental impact control by automatically collecting, storing, and reporting engine run data
6) Interface with the engine data management concepts to support Engine Life Management.

Implementation

To achieve the overall system benefits the JETS was structured as a two-phase program. In Phase I the AJETS hardware and software is integrated into the test cell to demonstrate the concepts and collect cost and benefit data. In Phase II the hardware and software are further developed to meet the system requirements. In addition, integration and installation in all Air Force test cells and cabs will be achieved.

AJETS has been installed in the TF39 test cells at Travis A.F.B and Dover A.F.B. The following paragraphs will describe the system hardware and software features. These features are described in terms of the test cell interface and benefits.

Prior to AJETS Installation

The test cell at Travis A.F.B. prior to installation of the AJETS is shown in Figure 1. In addition to the controls and indicators for engine and test cell control during an engine run, the photo shows the manual stick throttle, the display for computer prompts, and the camera monitor.

Figure 1. Travis Test Cell Before AJETS

System Overview

The objective of the AJETS installation in the TF39 test cells was to replace existing instrumentation, consisting primarily of ETTAS instrumentation, with modern, reliable instrumentation with improved software capabilities. To implement JETS, each test cell is modified to the AJETS configuration. A network is established to upload and download data to each test cell and connect users and other databases to this network. Other databases include Engine Trending and Diagnostics (ET&D) and engine performance models. The AJETS consists of an Environmental Control Unit (ECU) that houses the data acquisition system, sensors and controls located in the engine run bay, and a workstation, data acquisition system, vibration monitor, and throttle control located in the control room. Wireline telemetry is used to control the data acquisition system and communicate engine and test cell data from the run bay to the control room.

Subsystems of the AJETS as installed in TF39 test cells include instrumentation located in the engine bay, which included:

1) The L-3 Communications Telecommunications and Instrumentation data acquisition system, which includes the environmental control unit and integral pressure transducers

2) The stepper motor and resolver supplied by Process Control Technology

Subsystems located in the control room shown in Figure 2 include:

1) Automated Data Acquisition System (ADAS 5000™) developed by L-3 Communications

2) The Sun workstation and flat panel display

3) The throttle control computer and the stepper motor drive/translator developed by PCT

4) A Mechanical Technology, Inc (MTI) vibration analysis system.

Figure 2. Control Room Instrumentation

Control Room Signal Conditioning

The primary system located in the control room is the Data Acquisition System (DAS) that includes a digital and analog interfaces. The primary interfaces are the two serial interfaces to DAS located in the engine bay, one for data acquisition (co-ax Hot Link™) and the other for programming (RS-422). Digital interfaces are used to receive the digitally encoded throttle angle and discrete overheat signals. The analog interface receives the vibration signals from the vibration analysis system.

Engine Bay Signal Conditioning

The signal conditioning mounted in the engine bay is shown in Figure 3. This photo shows pressure signal calibration being performed by PMEL personnel.

Figure 3. Engine Bay Mounted Signal Conditioning

The photo shows the Environmental Control Unit, an enclosure housing a Data Acquisition System. The ECU conditions the air within the enclosure through use of a heat exchanger. The enclosure provides front access to signal conditioning circuit cards assemblies, rear access to wiring between bulkhead connectors and signal conditioning cards.

The signal conditioning rack houses Universal Signal Conditioning Amplifiers (USCAs). The USCA can be remotely programmed with algorithms to match the sensors in the test cell or on the engine. At the heart of the USCA are programmable gain amplifiers, filters, analog-to-digital converters, and digital signal processors. The AJETS employs an 8-channel configuration. The USCAs were originally developed in conjunction with National Aeronautics and Space Administration (NASA) engineers, and used innovative methods to reduce costs while maintaining performance and safety. Additional information on the capabilities and application of USCAs and the ADAS 5000™ is provided in Ref. 1.

Throttle Subsystem

The throttle system installed in the TF39 engine test cell consists of the following components:

1) A stepper motor mounted in the engine adapter to drive a pulley on the cable attached to the engine throttle assembly.
2) A resolver mounted in the engine adapter to read the angle of the pulley.
3) A Master Control Unit (MCU) mounted in the control room to provide closed-loop control of the engine throttle. The MCU is an industrial grade computer that controls the interface for the motor translator, resolver angle feedback, and Controller. The MCU has additional interfaces for either digital or RS-232 remote control of throttle position.
4) A Control Unit located in front of the operator, for convenient, safe engine throttle position control and feedback.
5) A Translator that commands the stepper motor.
6) An interface cable set.

In the context of system benefits, the throttle provides computer control of an interface previously manually controlled. Computer control of the throttle makes uniform and smooth throttle control possible, thereby enabling repeatable Turbine Inlet Temperature margins and vibration spectra. These enhancements will allow increased visibility into bearing and accessory vibration. In addition, repeatability of temperature margins (Quality) will add to the development and refinement of fleet wide performance measures and metrics. The throttle Control Unit is shown in Figure 4.

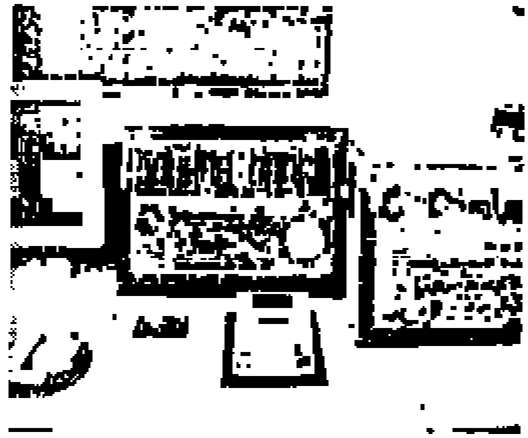

Figure 4. Throttle Controller

Vibration Subsystem

The TF39 has four engine-mounted vibration transducers. Two are basic engine accelerometers. The one mounted on the rear compressor frame monitors core vibration, whereas the one mounted on the rear turbine frame monitors fan vibration. Two velocity pickups are also installed during test on vibration pads 180 degrees rotation from the accelerometer pads.

A charge amplifier, located in the engine bay, conditions and converts the charge signals from the two accelerometers into velocity signals. Four velocity signals are wired into a vibration analysis system located in the control room. The existing vibration analysis system installed in the TF39 test cells uses the MTI PBS-4100™. The PBS-4100™ features both balancing and vibration analysis algorithms.

The balancing algorithms are used to balance the fan of the TF39 high bypass engine. The vibration phase relative to tachometer phase is used to predict the best the location for installing balancing weights. Algorithms are engine-specific and tailored to include such information as bolt hole location and weight increments.

The vibration analysis system includes tracking filters whose center frequencies are at the fan and core speeds, and displays both for broad band and tracked vibration outputs. Output formats include numeric, spectrums (vibration vs frequency), vibration surveys (vibration vs speed), waveform (vibration vs time). Figure 5 shows the vibration survey as seen on the PBS-4100R™.

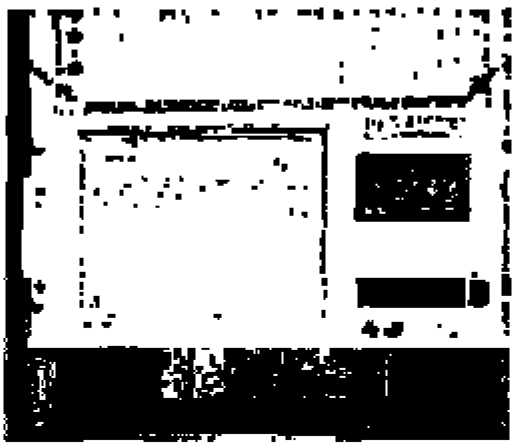

Figure 5. Vibration Survey for TF39 Engine

In the context of meeting system requirements, the vibration data is available to diagnose problems both real-time through an analog input to the data acquisition system, and over Ethernet. As part of the Phase II program effort, routines will be developed to relate frequency and amplitude of vibration to specific rotating components on the engine. The use of waterfall plots, a comprehensive fleet-wide database, and implementation of signal conditioning at the engine are expected to yield benefits of improved signal quality and diagnostic capability.

Test Program

The test program is an automated implementation of the engine test Technical Order. The test program identifies testing to be accomplished on the engine and performs the following functions:

1) Display real-time engine data to the operator
2) Allow operator selection of test sequencing
3) Sequence the test
4) Detect and display alarms
5) Detect and display test pass/fail conditions
6) Capture data
7) Print test results

The critical display for the operator is shown in Figure 6

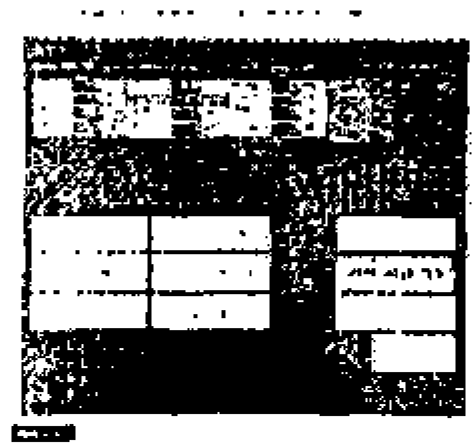

Figure 6. Critical Display

In the Phase I implementation the test sequence is semi-automated in that the operator is requested to perform certain operations while the system monitors engine performance. In Phase II the test sequence will be fully automated to include test program control of the engine throttle and the engine and test cell controls and actuators.

Advanced Diagnostics

Advanced diagnostics for the JETS program will be implemented as part of the Phase II effort. Vibration and other operational diagnostics are the starting point for reducing engine operating and maintenance costs. Diagnostics and prognostics will include the following:

1) Relating excessive vibration to rotating engine components and accessories
2) Using sensor validation routines to separate test cell sensor failures from engine operational problems
3) Using real-time performance data analysis to isolate engine problems
4) Using shared engine analysis and engine models of the gas path to improve engine

performance testing and make force-wide decisions

Data Management

The key to reducing overall operating and support cost is a network of shared resources. Each test cell will be networked to a central engine test cell host site. Download of software and performance metrics, and upload of test data and results is scheduled as part of Phase II. Design consideration is being given to areas of security and access, data flow and size, and data content including metrics.

Each test cell consists of a local network that linked the Sun workstation, System 500 data acquisition system, and PBS-4100™ vibration analyzer. In addition to the access provided to each test cell local network, the host computer must gain or provide access to other systems. The systems will include: 1) engine trending sites for correlation of flight data with test cell data on an individual Engine Serial Number (ESN) basis or a TMS basis; 2) using commands access to engine metrics and test cell metrics; and 3) propulsion engineering access to engine performance data, engine modeling, and simulation capabilities.

Conclusions

The capabilities of the AJETS to satisfy system requirements of reduced support costs and improved engine testing and accountability are being demonstrated during Phase I. The initial findings are favorable in the quality of the signals, capabilities to store and network data, and self-calibration. Additional data will be collected during Phase I to determine the cost and performance benefits.

REFERENCES

[1] Gladney, Ed. "NASA Launches an Automated Data Acquisition System", Sensors, September 1996.

1. WHAT TYPE OF CONTRACTUAL COMMITTMENT CURRENTLY EXISTS FOR THE AF ON THIS PROCUREMENT WITH L-3 COMMUNICATIONS?

We have an OT (Other Transaction) agreement supported by ASC for DARPA Other Transactions are agreements used for research and prototype projects that are principally defined in terms of what they are not. They are not a contract, grant, or cooperative agreement. To the extend that a statute or regulation is limited in its applicability to the use of a contract, grant or cooperative agreement, it generally does not apply to an Other Transaction. For example, the Contracts Disputes Act and the Federal Acquisition Regulation do not apply to Other Transactions. The National Defense Authorization Act for FY97 provided the Secretaries of the military departments OT authority to carry out prototype projects OTs are non FAR based agreement which provide greater flexibility and enhanced government participation with commercial industry. Section 845 of Public Law 103-160, as modified by Section 804 of Public Law 104-201, provides the Secretary of the Air Force authority to enter into transactions (other than contracts) under 10 U.S.C 2371 for prototype projects directly relevant to weapons or weapon systems proposed to be acquired or developed by the DoD. This authority terminates 30 Sep 99 unless extended by Congress. The Air Force Deputy Assistant Secretary for Contracting (SAF/AQ) policy memorandum, 6 May 97, provides Air Force guidance for executing an OT for prototype program.

More info regarding OT can be found on the HQ AFMC/PKT home page at

2. WHAT IS AF COMMITTMENT WITH COSSI?

To compete for selection into the COSSI program requires that a detailed, properly formatted proposal be presented to DoD for evaluation. In this proposal, the purpose of Stage 1 must be defined. The purpose of Stage 1 is to prove that after inserting four prototype kits into the existing test cells, we will be able to demonstrate the proposed operations and support savings previously predicted and/or calculated. In addition, the insertion of these kits will not impede or degrade the existing test cell's performances. Based on the demonstration of operations and support savings as predicted and the fact that insertion of the kits does not impede any of the operations, we may proceed to stage 2. When we decide to transition to Stage 2, we have a good faith commitment to acquire these kits on a sole source basis from L-3 Communications.

3. WHEN IS STAGE 1 CONSIDERED "SUCCESSFUL"?

There are several factors to be considered, 1) Technical Success - Is the L-3 Acquisition System able to technically support all of the inputs from the existing engine sensors, does it provide the proper readouts at the appropriate time, is it capable of supporting the storage and transmittal of the data, etc. These are